CHILEAN JOURNAL of AGRICULTURAL RESEARCH

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RESEARCH ARTICLE

Effects of potassium and boron fertilization on sunflower yield, oil content, and quality

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Received: 28 March 2024; Accepted: 10 July 2024, doi:10.4067/S0718-58392024000600729

ABSTRACT

Potassium (K) and B are important for phloem translocation, reproductive growth, and grain formation. A 2-yr field study was conducted to evaluate the effect of K and B applied through the soil and foliar application on sunflower (*Helianthus annuus* L.) Experiments included the soil application of K (62 kg ha^{-1}) and B (5 kg ha^{-1}) and foliar spray of K (1%) and B (0.1%). Furthermore, the soil-applied K and B was supplemented with three foliar sprays of either K, B, or both at 45, 60 and 75 d after sowing. The results revealed that K and B fertilization improved the agronomic parameters of sunflower, including plant height, head diameter, achenes per head, achene weight, yield, seed oil contents and oil quality. The soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS resulted in production of taller plants (192 and 172 cm), head diameter (23 and 28 cm), achene per head (954 and 1063), 1000 achene weight (68 and 67.58 g), achene yield (2976 and 2621 kg ha^{-1}), biological yield (11363 and 8430 kg ha^{-1}), oil contents (43.37% and 41.87%), and oleic acid (70.33% and 80.83%) over 2 yr of study. Hence it can be concluded that soil application of 62 kg ha^{-1} K followed by foliar application of 1% K + 0.1% B is the preferable fertilization strategy for sunflower for improved yield, seed oil contents, and oil quality.

Key words: Fertilization strategy, foliar nutrient application, *Helianthus annuus*, omega-6, omega-9, sunflower seed oil.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is an important oilseed crop because of its higher quantity and premium quality oil contents. Seeds of sunflower botanically called achene contain 40%-50% oil and 20%-27% proteins (Çetin et al., 2021). The oil of sunflower is excellent in quality as it contains a high percentage of unsaturated fatty acids and they are useful for heart diseases patients (González-Rámila et al., 2022). Extraordinary qualities sunflower oil is near to olive oil.

Edible oil is a major import item of Pakistan. Only 18% of demand is fulfilled through local production while the remaining 82% is imported from other countries. During 2021-2022, 2.968 million tons were imported worth 3.217 billion USD while local production was recorded up to 0.507 million tons (MNFSR, 2022). There is a dire need to boost local edible oil production so that import bills may be reduced. Sunflower crop has

immense potential in this regard as it can be cultivated twice a year. Moreover, sunflower contributes 16% to local edible oil production in Pakistan (Iqbal et al., 2022).

Pakistan is bestowed with different agroecological zones and sunflower have good adaptability in these zones (Yaseen et al., 2022). In Pakistan, during 2020, sunflower was sown at an area of 88 660 ha and seed yield was 105 000 t. The average yield of sunflower is quite low compared to other countries. Imbalance use of fertilizer and non-application of K and micronutrients are major factors for low yield. Proper plant nutrition is an integral part of sunflower production system to achieve potential yield and economic benefits (Vilvert et al., 2023). Sunflower has a large flower and it faces acute deficiency of K and B during grain filling and formation (Paul et al., 2021).

Potassium plays several metabolic functions in plants and it has a key role in enzyme activation. At least 40 enzymes are activated by K in plants. Moreover, K improves water relations of plants and is a main signal in stomatal regulation. Osmotic adjustment under water and salinity stress is a major physiological function of K (Farouk and Al-Huqail, 2022). Pakistan is going to be intensive in agriculture to meet the challenge of food security. Crops which need K in large quantities are abundant in our cropping systems. So, in Pakistan soils are now deficient in available K. Application of adequate K fertilizer is necessary to harvest proper yields (Tang et al., 2021).

Potassium has beneficial effects on the accumulation of polyunsaturated fatty acids which is a key parameter for good quality oil (Rabail et al., 2021). An adequate supply of K improves the redistribution of assimilates thereby increasing achenes per capitulum, achene weight, and oil yield (Modanlo et al., 2021; Wang et al., 2023). Adequate K supply increases not only productivity and growth of sunflower but also enhances tolerance against drought stress conditions (Mehrparvar et al., 2021; Traspadini et al., 2022). Great resistance against drought stress conditions, more allocation of assimilates to grains, and higher yield were observed in sunflower plants with an abundant supply of K as compared to K-deficient plants (Bellido et al., 2021).

Soils in Pakistan are alkaline in nature and particularly deficient in micronutrients including B. About 50%-60% of Pakistani soils are B deficient (Murtza et al., 2022). Boron has multidimensional roles in plant biology and function. Meristematic tissues require B for growth, and it is essential for pollen germination and cell division (Rehman et al., 2018). It is required for the normal functioning and stability of cell membranes by binding glycolipids (Wang et al., 2022). Interaction between the plasma membrane and B is manifested through obstruction of membrane-bounded oxidoreductase activities (Zhang et al., 2022). Additionally, it has a pivotal role in cell wall strengthening and when plants are deficient in B, the ratio of cellulose, hemicellulose, and pectin changes thus decreasing cell wall strength (Bi et al., 2022). Boron being an integral component of the sugar-borate complex facilitates sugar transport whereas the efflux of glucose and ribonucleosides is controlled via artificial bilayer membranes by boronic acid (Debiais et al., 2022). An adequate supply of B enhances the translocation and redistribution of assimilates to growing points and fruits thus increasing economic yield. Application of B enhances fruit set thereby increasing yield in sunflower (Kohli et al., 2022). In addition, foliar application of B under drought conditions increased biological yield, harvest index, and seed B content (Imran and Amanullah, 2021).

Many reports are available regarding the individual effects of B and K on sunflower yield and oil quality. Nonetheless, studies regarding the combined application of both nutrients through soil and foliar application in sunflower are rare. Therefore, the present study was planned to evaluate the effect of K and B via soil and foliar application on sunflower yield contributing traits, seed oil contents, and quality.

MATERIALS AND METHODS

Experimental setup and crop husbandry

The experiment was conducted in the research area of the Vegetables and Oilseeds Section, Agronomic Research Institute, Faisalabad, Pakistan, in February 2019 and 2020. Sunflower (*Helianthus annuus* L.) hybrid 'FH-516' collected from Oilseeds Research Institute, AARI Faisalabad, was used as plant material. A randomized complete block design was used for the experiment. The experimental treatments comprised of either soil or foliar application of K or B. The soil-applied fertilizers were supplemented with foliar spray of either K, B, or both. The details of the experimental treatment plan are presented in Table 1.

Table 1. The experimental treatment plan for K and B fertilization in sunflower.

Treatments	Description
T_1	Control
T_2	Soil applied K at 62 kg ha^{-1}
T_3	Soil applied B at 5 kg ha^{-1}
T_4	Soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K at 45, 60 and 75 d after sowing (DAS)
T_5	Soil applied B at 5 kg ha^{-1} followed by foliar spray of 0.1% B at 45, 60 and 75 DAS
T_6	Soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS
T_7	Soil applied B at 5 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS
T_8	Foliar spray of 1% K at 45, 60 and 75 DAS
T_9	Foliar spray of 0.1% B at 45, 60 and 75 DAS

Soil sample was taken at two depths viz., 15 and 30 cm, and analysis was carried out for soil physio-chemical properties as per AOAC (2005) and results are presented in Table 2. Weather data was obtained from Meteorological Observatory, Ayub Agricultural Research Institute, Faisalabad, Pakistan. Sunshine hours, relative humidity, and mean temperature for the sunflower growing season were averaged monthly. While rainfall data is the total rainfall received during the respective months (Table 3).

Table 2. Soil physio-chemical properties of the experimental site. EC: Electrical conductivity; OM: organic matter; AP: available P; AK: available K; AB: available B.

Serial	pH	EC	OM	AP	AK	AB	Texture
		dS m^{-1}	%	mg kg^{-1}			
1-A (0-15 cm)	7.4	2.78	0.98	8.9	160	0.15	Loam
1-B (0-30 cm)	7.5	2.22	0.77	8.0	115	0.13	Loam
2-A (0-15 cm)	7.5	2.06	0.91	8.2	140	0.14	Loam
2-B (0-30 cm)	7.5	1.91	0.91	8.0	90	0.11	Loam

Table 3. Weather data for the sunflower season of 2019 and 2020.

					Monthly temperature							
	Rainfall		Relative humidity		Maximum		Minimum		Mean		Sunshine	
Months	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
	mm		%		°C						h	
February	56.8	24.8	69.75	64.00	20.5	23.8	8.0	8.7	14.25	16.25	5-56	7-21
March	39.6	13.5	60.85	73.70	26.1	24.5	12.7	13.9	19.40	14.00	6-52	6-06
April	33.6	20.6	50.85	60.70	35.2	33.1	20.1	18.8	27.65	25.95	8-25	8-57
May	31.6	19.9	39.00	44.95	38.7	37.5	23.0	23.1	30.85	30.30	9-53	9-35
June	29.3	69.8	37.60	54.55	41.4	39.9	26.3	25.8	33.85	32.85	10-00	9-27

Sunflower hybrid FH-516 was sown on 75 cm apart ridges with a plant-to-plant distance of 15 cm using a dibbler. Fertilizers were applied at 150-100 NP kg ha^{-1}. Urea and diammonium phosphate were used as fertilizer sources. All P was applied at the time of sowing whereas 1/3 N was applied at sowing and the remaining N was applied in two splits. Potassium and B were applied as per treatment; K_2SO_4 and boric acid were used as sources for K and B. For foliar application, 1% solution of K was prepared from K_2SO_4 and 0.1% B was prepared from boric acid. These solutions were applied 45, 60, and 75 d after sowing as per treatment. To maintain plant population and keep plants healthy, thinning was done at 3-4 leaf stage. Other agronomic practices were kept uniform. Recommended practices were followed to control weeds and plant protection measures were taken to make the crop disease and insect free.

Agronomic and oil quality-related parameters

Five plants were harvested at maturity from each plot at ground level and their height was recorded from ground level to the top of the plant with measuring tape and then the average was obtained. The head diameter of five plants was recorded from each treatment and then the average was taken. The heads were detached from the stem, sun-dried, and threshed individually and the number of achenes were counted with a seed counter. The 1000 achene weight was recorded with digital electric scale for each treatment. Complete plots were harvested at maturity and plants were tied into bundles and then sun-dried for a week. Then dry weight was recorded per plot and per hectare, the biological yield was calculated. The achene yield per plot was recorded. The capitula were separated from plants and shelled manually. Then separated achenes from each plot were weighed individually and converted to per hectare yield. The harvest index indicates the ratio of grain yields to biological yield and was calculated by the following formula:

$$Harvest\ index\% = \frac{Achene\ yield}{Biological\ yield} \times 100$$

Oil contents, oleic acid % (omega-9), and linoleic acid % (omega-6) were measured through near infrared (NIR) technology (Perten, DA7250S/N/1821904, Perkin Elmer, Waltham, Massachusetts, USA).

Statistical analysis

The data collected on all parameters were statistically analyzed by using Fisher's ANOVA technique. Tukey's HSD test at a 5% probability level was applied to compare the treatment's means using STATISTIX 8.1 (Analytical Software, Tallahassee, Florida, USA). Figures were drawn using SigmaPlot 14.0 (SPSS, Chicago, Illinois, USA) and R studio 4.6.1 (R Studio, Boston, Massachusetts, USA).

RESULTS

Various agronomic, seed oil contents and quality-related attributes of sunflower were evaluated during both years of study and are presented in this section.

Plant height (cm)

Sunflower depicted a significant ($p < 0.05$) increase in plant height by the application of K and B during both years (Table 4). Application of K and B increased the plant height in the range of 10%-11% and 4%-6%, respectively, over control by soil and foliar application. Nonetheless, the maximum increase in plant height was observed when soil K application was supplemented with foliar spray of K and B. That resulted in a 23% increase in plant height than the control averaged over both years of study.

Head diameter (cm)

Sunflower delineated a significant ($p < 0.05$) increase in head diameter by the application of K and B during both years. Application of K and B elevated the head diameter in the range of 30%-40% and 6%-10%, respectively, as compared to the control by soil and foliar application. However, the maximum increase in head diameter was observed when soil K application was supplemented with foliar spray of K and B (Table 4). That resulted in 1.8 times increase in head diameter relative to control averaged over both years of study.

Achenes per head

Sunflower showed a significant ($p < 0.05$) increase in number of achenes per head by the application of K and B during both years. Application of K and B increased the number of achenes per head in the range of 35%-43% and 17%-23%, respectively, over control by soil and foliar application. Nonetheless, the maximum increase in number of achenes per head was observed when soil K application was supplemented with foliar spray of K and B. The number of achenes per head contrasted to the control increased by 63% on average over both years of study (Table 4).

1000 Achenes weight (g)

Sunflower depicted a significant ($p < 0.05$) increase in 1000 achenes weight by the application of K and B during both years (Table 4). Application of K and B increased the 1000 achenes weight in the range of 18%-27% and 5%-13%, respectively, over control by soil and foliar application. Although, the maximum increase in 1000 achenes weight was observed when soil K application was supplemented with foliar spray of K and B. That resulted in 1.5 times increase in 1000 achenes weight than control averaged over both years of study.

Achene yield (kg ha^{-1})

Sunflower represented a significant ($p < 0.05$) increase in achene yield by the application of K and B during both years. Application of K and B increased the achene yield in the range of ~ 20% and 6%-18%, respectively, over control by soil and foliar application. Nonetheless, the maximum increase in achene yield was observed when soil K application was supplemented with foliar spray of K and B. This treatment resulted in a 50% increase in achene yield over control on average during both years of study (Table 4).

Biological yield (kg ha^{-1})

Sunflower depicted a significant ($p < 0.05$) increase in biological yield by the application of K and B during both years. Application of K and B increased the biological yield in the range of 34%-54% and 8%-16%, respectively, over control by soil and foliar application (Table 4). Although, the maximum increase in biological yield was observed when soil K application was supplemented with foliar spray of K and B. The biological yield was enhanced by 1.8 times on average over control in both years of study.

Table 4. Effect of various K and B fertilization practices on agronomic parameters of sunflower. T_1: Control; T_2: soil applied K at 62 kg ha^{-1}; T_3: soil applied B at 5 kg ha^{-1}; T_4: soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K at 45; 60 and 75 d after sowing (DAS); T_5: soil applied B at 5 kg ha^{-1} followed by foliar spray of 0.1% B at 45, 60 and 75 DAS; T_6: soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS; T_7: Soil applied B at 5 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS; T_8: foliar spray of 1% K at 45, 60 and 75 DAS; T_9: foliar spray of 0.1% B at 45, 60 and 75 DAS.

	Plant height		Head diameter		Achenes per head		1000 achenes weight		Achene yield		Biological		Harvest index	
Treatments	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
	cm		cm		g		g		kg ha^{-1}		kg ha^{-1}		%	
T_1	147^{h}	149^{h}	14.64^{h}	14.00^{h}	575^{g}	664^{f}	48.95^{g}	44.59^{g}	2045^{e}	1667^{f}	6905^{f}	3987^{h}	24.89^{f}	19.90^{g}
T_2	166^{d}	164^{cd}	18.46^{d}	21.66^{d}	812^{cd}	963^{b}	59.80^{c}	58.80^{c}	2575^{bcd}	1882^{e}	9891^{b}	6838^{c}	37.79^{bc}	31.90^{c}
T_3	152^{gh}	155^{g}	15.27^{gh}	15.00^{gh}	661^{fg}	786^{e}	51.35^{f}	47.03^{f}	2107^{e}	1811^{e}	7490^{ef}	4319^{gh}	28.32^{ef}	21.79^{fg}
T_4	181^{b}	169^{b}	20.33^{b}	25.00^{b}	894^{ab}	1044^{a}	63.86^{b}	65.77^{a}	2881^{ab}	2540^{a}	10531^{b}	7332^{b}	42.48^{ab}	37.02^{ab}
T_5	158^{ef}	159^{ef}	16.48^{f}	17.33^{f}	728^{ef}	881^{cd}	52.73^{ef}	53.00^{de}	2371de	2419^{b}	8304^{d}	5160^{ef}	34.92^{cd}	23.50^{de}
T_6	192^{a}	172^{a}	23.00^{a}	28.00^{a}	954^{a}	1063^{a}	68.00^{a}	67.58^{a}	2976^{a}	2621^{a}	11363^{a}	8430^{a}	44.45^{a}	39.67^{a}
T_7	174^{c}	166^{bc}	19.33^{c}	23.33^{c}	855^{bc}	995^{ab}	60.89^{c}	62.14^{b}	2721^{abc}	2200^{c}	10115^{b}	6294^{d}	39.34^{abc}	35.88^{b}
T_8	164de	161de	17.46^{e}	19.66^{e}	764de	934^{bc}	55.73^{d}	54.95^{d}	2431^{cde}	2010^{d}	9079^{c}	5542^{e}	36.26^{cd}	29.23^{cd}
T_9	155^{fg}	158^{f}	15.86^{fg}	15.66^{g}	696^{ef}	826de	53.82^{e}	51.55^{e}	2295^{e}	2095^{d}	7925de	4769^{fg}	31.46^{de}	23.52^{e}
Tukey's HSD (0.5)	5.43	2.86	0.73	1.2	70	73	1.37		339	102	2.15	451	5.65	3.45

Harvest index (%)

Sunflower showed a significant ($p < 0.05$) increase in harvest index by the application of K and B during both years (Table 4). Application of K and B increased the harvest index in the range of 46%-55% and 12%-23%, respectively, over control by soil and foliar application. Nonetheless, the maximum increase in harvest index was observed when soil K application was supplemented with foliar spray of K and B. That resulted in an 88% increase in harvest index than control averaged over both years of study.

Oil contents (%)

Sunflower showed a significant ($p < 0.05$) increase in oil contents by the application of K and B during both years. Application of K and B increased the oil contents in the range of 11%-12% and 3%-7%, respectively, over control by soil and foliar application. However, the maximum increase in oil contents was observed when soil K application was supplemented with foliar spray of K and B. That resulted in 1.2 times increase in oil contents than the control averaged over both years of study (Table 5).

Table 5. Effect of various K and B fertilization practices on oil contents, oleic and linoleic acid contents of sunflower. T_1: Control; T_2: soil applied K at 62 kg ha^{-1}; T_3: soil applied B at 5 kg ha^{-1}; T_4: soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K at 45; 60 and 75 d after sowing (DAS); T_5: soil applied B at 5 kg ha^{-1} followed by foliar spray of 0.1% B at 45, 60 and 75 DAS; T_6: soil applied K at 62 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS; T_7: Soil applied B at 5 kg ha^{-1} followed by foliar spray of 1% K + 0.1% B at 45, 60 and 75 DAS; T_8: foliar spray of 1% K at 45, 60 and 75 DAS; T_9: foliar spray of 0.1% B at 45, 60 and 75 DAS.

Treatments	Oil content 2019	Oil content 2020	Oleic acid (omega-9) 2019	Oleic acid (omega-9) 2020	Linoleic acid (omega-6) 2019	Linoleic acid (omega-6) 2020
	%	%	%	%	%	%
T_1	36.49^{h}	33.42^{f}	55.45^{f}	54.41^{g}	38.52^{a}	34.07^{a}
T_2	40.73^{cd}	37.85^{cd}	63.97^{cd}	68.45^{cd}	26.85^{e}	22.51^{ef}
T_3	37.54^{g}	34.42^{ef}	57.75^{f}	56.76^{fg}	35.25^{b}	30.05^{b}
T_4	41.73^{b}	39.96^{b}	67.85^{ab}	75.34^{b}	19.95^{g}	19.69^{g}
T_5	39.83^{de}	36.47^{de}	61.44^{e}	61.41^{ef}	29.57^{d}	25.34^{cd}
T_6	43.37^{a}	41.87^{a}	70.33^{a}	80.83^{a}	17.78^{g}	17.53^{h}
T_7	41.09^{c}	38.36^{c}	65.94^{bc}	72.06^{bc}	22.97^{f}	21.38^{fg}
T_8	40.42^{de}	37.36^{cde}	62.65^{de}	64.84^{de}	28.30^{de}	23.52^{de}
T_9	38.88^{f}	36.09^{e}	60.56^{e}	58.73^{fg}	32.42^{c}	26.55^{c}
Tukey's HSD	0.62	1.46	2.51	5.24	2.69	2.08

Oleic acid (omega-9, %)

Sunflower depicted a significant ($p < 0.05$) increase in oleic acid by the application of K and B during both years (Table 5). Application of K and B increased the oleic acid in the range of 16%-20% and 4%-8%, respectively, over control by soil and foliar application. Nonetheless, the maximum increase in oleic acid was observed when soil K application was supplemented with foliar spray of K and B. Oleic acid increased by 1.4 times more than the control during both years of study.

Linoleic acid (omega-6, %)

Sunflower depicted a significant ($p < 0.05$) reduction in linoleic acid by the application of K and B during both years. Application of K and B decreased the linoleic acid in the range of 29%-33% and 10%-19%, respectively, over control by soil and foliar application. Nonetheless, the maximum reduction in linoleic acid was observed when soil K application was supplemented with foliar spray of K and B. That resulted in a 51% reduction in linoleic acid than the control averaged over both years of study (Table 5).

Correlation matrix and principal component analysis

A correlation matrix was carried out among various parameters of sunflower. Figure 1 depicted that there was a steady increase in oil contents and omega-9 % with an increase in achene yield. However, the omega-6 % decreased as the sunflower achene yield was improved due to proper K and B fertilization. Principal component analysis was carried out around all studied variables to determine the influence of K and B application on sunflower (Figure 2). Two components, PC1 and PC2, were subjected to analysis. The total variance was shared in the range of 36.9% and 17.8% by PC1 and PC2, respectively. The analysis showed that omega-6 % possessed a negative correlation with agronomic parameters of sunflower and seed oil contents.

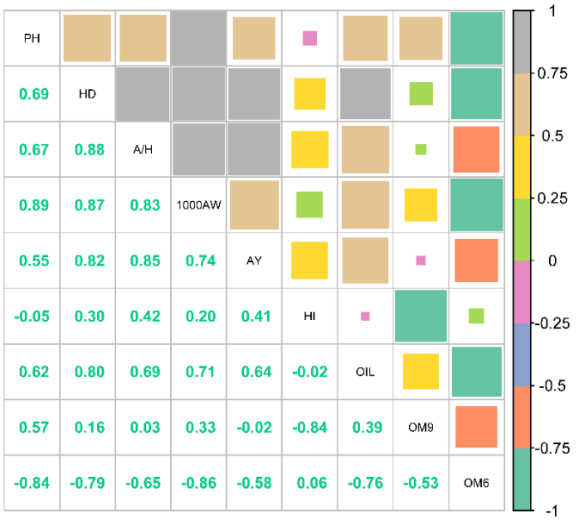

Figure 1. Correlation matrix between various parameters of sunflower subjected to various K and B fertilization strategies. PH: Plant height; HD: head diameter; A/H: achenes per head; 1000AW: 1000 achene weight; AY: achene yield; HI: harvest index; OIL: oil contents; OM9: omega-9; OM6: omega-6.

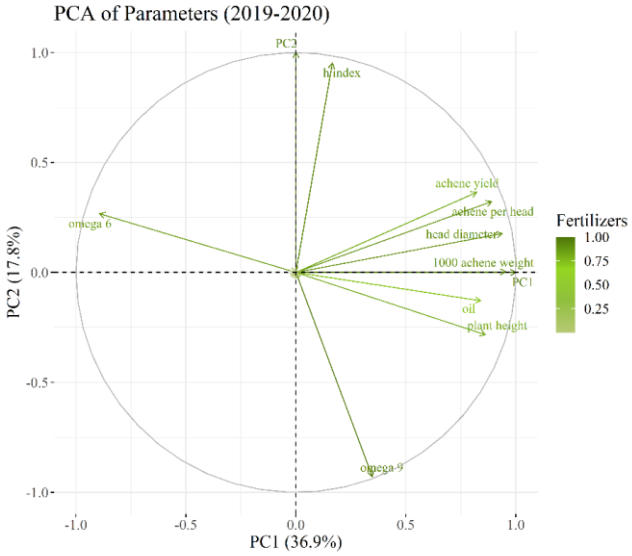

Figure 2. Principal component analysis of variables under study during both years.

DISCUSSION

Nutrient management plays a significant role in the yield, oil contents, and oil quality of sunflower. The results of the present study revealed that K and B nutrition is essential to increase achene yield and better-quality oil of sunflower. The agronomic parameters of sunflower including plant height, head diameter, number of achenes, achene weight, and yield significantly improved by the K and B fertilization. It is interesting to note that soil K application followed by foliar spray of K and B recorded a maximum of the above-mentioned parameters. Application of K is essential for plants to attain proper plant height and head diameter, as a short supply of these nutrients can limit plant growth which can result in short sunflower plants with smaller heads (Xie et al., 2021). Head diameter increased with soil application of K combined with foliar application of K and B. Wasaya et al. (2021) reported that foliar application of B at vegetative and anthesis stages increased head diameter substantially.

The number of achenes was maximum for treatment in which soil-applied K was assisted by foliar application of K and B and for treatment in which K was applied through the soil along with the foliar application of same. Ertiftik and Zengin (2016) observed that yield components and the number of achenes per head were strongly improved by increasing doses of K in sunflower. Koutroubas et al. (2020) recorded a positive increase in the number of achenes per head in sunflower by K application. Achene weight was enhanced by soil application combined with foliar application of K and B. Increase in achene weight by proper K fertilization has been reported by several studies (Li et al., 2018). Furthermore, the role of B fertilization in increasing achene weight is documented in literature (Wasaya et al., 2021).

Maximum achene yield was recorded by soil K application followed by foliar sprays of K and B. Our results agree with Shafiq et al. (2021), who reported that K enhances achene yield in sunflower by redistribution of assimilates. It is reported that foliar application of B increased achenes yields by enhancing fruit setting in sunflower (Kosar et al., 2021). Mokhtari et al. (2022) observed that the highest achene yield was recorded in sunflower by two foliar applications of B, one at the vegetative stage and one at the anthesis stage.

The maximum biological yield was recorded for treatment in which soil-applied K was assisted by foliar application of K and B and for treatment in which K was applied through the soil along with the foliar application of K. Dry matter production in sunflower increased by an adequate supply of K and DM accumulation retarded under K deficiency (Dar et al., 2021). Biological yield is an outcome of different growth processes such as cell division, cell elongation, and biomass accumulation and B has a major functional role in all these processes as an increase in biological was recorded by the application of B.

Improvement in harvest index (HI) of sunflower was observed by the application of K and B fertilization as achene weight and yield was improved. Positive modifications in HI by the K and B fertilization in sunflower has been reported (Mehrparvar et al., 2021). The K application increased oil contents significantly. Abbadi et al. (2008) observed that oil contents in sunflower are sensitive to K availability. Modanlo et al. (2021) indicated that K application increased oil percentage in sunflower. Foliar application of B enhanced oil contents of sunflower. Thakur et al. (2023) reported improvement in oil contents by foliar application of B. Oleic acid is enhanced by the application of K. Oleic acid percentage is an indicator of good quality edible oil, so K fertilization improves oil quality in sunflower. Proper nutrient management of sunflower including K application improves the quality of sunflower oil by enhancing unsaturated fatty acids (Li et al., 2018). Furthermore, enhancement in oleic acid in sunflower oil has been reported by foliar B application (Rehman et al., 2018).

Linoleic acid is not desirable in edible oil, as with an increase in linoleic acid percentage risk of chronic heart diseases also increases. However, the proper nutrient application reduces the linoleic percentage and improved the quality of sunflower oil. Ullah et al. (2019) demonstrated that K application does not increase linoleic acid in sunflower. Improvement in oil quality was observed by B fertilization in olive cultivation (Vishekaii et al., 2019).

CONCLUSIONS

It can be concluded that K and B fertilization is essential to get superior sunflower yield. The present study combined the effect of soil-applied K with subsequent foliar applications of K and B. The result revealed that all agronomic parameters including, plant height, head diameter, achene weight, yield, and oil quality were

improved with K and B fertilization. However, these improvements were more pronounced when soil K application was supplemented by foliar K and B sprays. Though, it elaborates on the possible synergistic effect of K with B for foliar application.

Author contribution

Conceptualization: B.H.B., M.N., M.Z.U.H. Experimentation: B.I., M.N., A.N.G. Analysis: B.H.B., M.N., M.T.A. Writing the original draft: B.I., M.N., A.N.G. Writing-review and editing: B.H.B., M.N., M.Z.U.H., M.U.H., S.G. All authors have approved the final version of the manuscript.

Acknowledgements

This project was supported by Researchers Supporting Project Number (RSP2025R5) King Saud University, Riyadh, Saudi Arabia.

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